Distributed Command and Control Research: Networking Multiple Simulation Platforms

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ABSTRACT: The United States Air Force is positioned to take full advantage of Internet2 technologies and apply them to Command and Control (C2) research. This paper summarizes and updates progress on the Air Force's Distributed Mission Training Research Network (DMT-Rnet), an Internet2 based network for collaborative research and training via distributed PC-based systems. This network hosts complex environments for multi-operator simulation-based training and performance research.

INTRODUCTION

In the Air Force Research Laboratory, a major research focus is the investigation and enhancement of operational expert training through a classified SIMNET-based infrastructure to enhance Distributed Mission Training (DMT). The USAF DMT program is national in scope,

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with the goal of enhancing operational training through high-fidelity military simulation systems that are networked using secure, classified systems.

DMT-RNet

In contrast, the DMT-Research Network (DMT-RNet) project is a local project that will support highly controlled and experimental basic research to support DMT through PC-based systems networked through the Internet. The project will establish an I-2 based infrastructure for collaborative research and training and identify specific research issues related to enhanced skill acquisition and operational performance. This research will guide improvements in the operational USAF DMT training environment (Barnes, Elliott & Entin, 2001).

The USAF DMT project relies on a network of highly realistic battle simulators that allow expert operators to train in a virtual battlespace across a highly secure and classified communication network. In contrast, DMT-RNet systems enable systematic investigations in unclassified mode and establish the infrastructure to conduct multi-level investigations of operational performance using less costly PC-based systems. The DMT-RNet collaborative research program will leverage emerging I-2 capabilities to connect distributed PC-based simulation systems and create complex environments for multi-operator training and performance research. These systems can be readily deployed to operational field settings and enable cost-effective distributed training wherever Internet access is available.

DMT-RNet systems will not be total replications of operational systems. Instead, these synthetic team task sytems will capture the cognitive and task demands of most interest to trainers and researchers (Elliott, Dalrymple, Regian., & Schiflett, 2001). Convincing arguments have been stated for the relevance of systems which are based on psychological fidelity, and the absolute need for internal validity for the advancement of scientific knowledge (Berkowitz & Donnerstein, 1982; Cook & Campbell, 1979; Mook, 1983). For example, a PC-based system may simplify the "button pressing" procedures required in an actual operational system and instead focus on display characteristics, decision making processes, tactics, strategies, and/or teamwork functionsInitial efforts developed PC-based platforms to represent the underlying cognitive and decision making task demands of Airborne Warning and Control System (AWACS) Weapons Director Teams, based on multiple investigations of cognitive and functional aspects of this performance domain (Coovert, et al., 1999).

The DMT-RNet also has the capabilities for integrating other PC-based simulators into its network, making possible a simulator interoperability that previously did not exist. This allows for flexible options of utilization of the network, with different levels of fidelity and classifications involved.

As a pioneering technology, DMT-RNet enables distributed and multidiscipline collaborations toward complementary research goals. Universities, agencies, and companies will be able to utilize a common platform, collected data in distributed settings, and pool their talents and resources to produce high level research. The applications of these concepts and technologies to other realms are nearly limitless, given imagination and initiative.

The DMT-RNet is an ideal technology jump for C2 research. It facilitates the gathering of information on resource allocation in the various C2 roles as well as how data is shared throughout the C2 levels. Barnes, Elliott, and Entin (2001) give an example where someone is playing the role of an Intelligence, Surveillance and Reconnaissance (ISR) operator. This person has control of various information-gathering tools, such as Predator Uninhabited Aerial Vehicles

(UAVs). The operator may send out these Predators to find specific targets or locations. Once found, the ISR operator sends this information to the person needing that information. It can be sent to everyone in his or her particular site, or to other individuals requiring that specific piece of information. As an example, someone playing a role in the Naval C2 team at the University of South Florida node can send a message to the person playing the role of the Joint Forces Air Component Commander at Brooks Air Force Base to request control of a KC-135 (refueling tanker). The JFACC can then switch control of the KC-135 to his naval counterpart working from the University of South Florida. Communication and resource allocation within and between the different sites can be closely monitored and documented. Analyses of communication and coordination data will reap enormous amounts of useful information on command, control, and communications process measures.

Demonstration of Distribution: Single Platform Example

The initial phase of the DMT-RNet project utilized the dynamic distributed decision making (DDD) team-in-the-loop simulation environment (Hess, MacMillan, Elliott, & Schiflett, 1999; Kleinman and Serfaty 1989). We developed an internet-based version of the DDD, the DDD Network (DDDnet), which allows players in distributed locations to connect and perform a distributed mission in real time (Barnes, Elliott & Entin, 2001). The DDDnet is an internet-ready version of a Linux-based collaborative gaming space that connects players to each other and to others, such as observers, confederates, trainers, or researchers. In the DDDnet observers at any location in the network are able to observe the scenario play in real time. They can view the screen display and electronic communications of any player, and communicate to one another via email or voice. In addition, the DDDnet can connect players to one another for interactive mission planning, debriefings and after-action reviews. Other internet-based systems have also been developed for specific training and research functions, within the scope of the DDD-Rnet project.

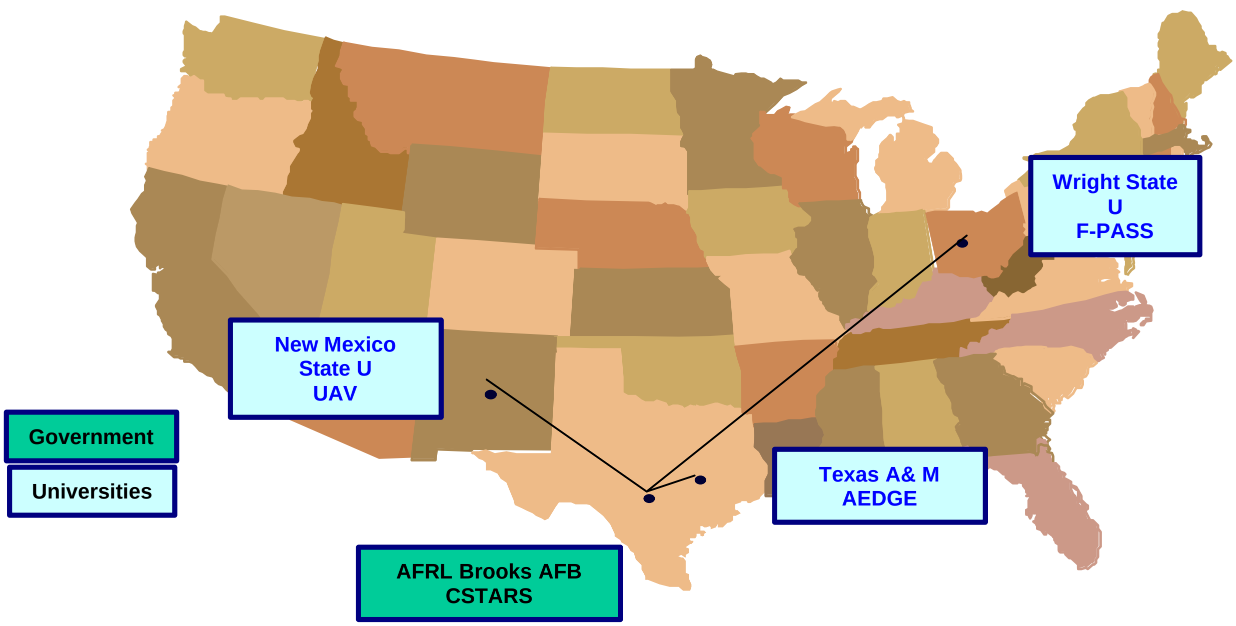
DDD simulations in general are based on broad command and control (C2) functions and have been demonstrated to elicit important team-oriented cognitive processes such as communication and coordination, resource allocation and sharing, and decisionmaking. For this initial effort, the DDD software and scenarios were developed as analogues to USAF operational performance domains. Specifically, this version of the DDDnet was developed to represent the underlying cognitive and decision making task demands of Airborne Warning and Control System (AWACS) Weapons Director Teams, based on multiple investigations of cognitive and functional aspects of this performance domain (Coovert et al., 2001). Further development resulted in a scenario that emulates three military C2 teams: the USAF AWACS team, another USAF ground-based C2 team, and a third Navy airborne C2 team.

The AWACS DDD-Net was implemented and demonstrated, allowing distributed simulations over the Internet. Aptima, a small research corporation, worked with faculty and staff at the University of Central Florida (and associated Institute for Simulation Technologies [UCF/IST]), the University of South Florida, and researchers located at Brooks Air Force Base to test the feasibility of the project (Entin, Serfaty, Elliott, & Schiflett, 2001). It linked the different locations, allowed multi-role missions, data collection, and feedback. Different parts of the network included I-2 connections for improved speed and performance. The DDDnet achieved and maintained a synchronized connection for an AWACS simulation involving 16 participants.

Simultaneously, observers at each location rated performance using web-based tools that allowed immediate data pooling, analysis, and feedback, within 10 minutes after data input was complete.

Interoperability: Connecting Different Platforms

The next effort of this project extended the interoperability capabilities, as well as developing an additional platform. While the previous effort connected several nodes located at various sites, the nodes were extensions of the same (DDD) platform. This next phase will connect several different platforms. The AWACS AEDGE™ (Agent-Enabled Decision Group Environment) is a simulation of the weapons director roles within the Airborne Warning and Control System. The C3STARS (Command, Control and Communications Simulation Training and Research System) facility is a high-fidelity representation of C3 functions. A UAV platform was also be connected, one developed at New Mexico State University, and a cadre of fighter-pilot simulations, using the 4-ship F-PASS (Flight Performance Assessment Simulation System). The following figure represents the participating agencies, locations, and platforms involved in this effort.



<u>AEDGE.</u> The AEDGE platform (Agent-Enabled Decision Group Environment) is a highly configurable C3 platform that uses intelligent agent technology to enhance simulation realism, decision support, and experimental manipulations. A unique aspect to the agent-based task is the capability of agents to "play" any role in a given scenario, thus allowing the study of individual performance in a complex but controlled team setting. Another aspect is voice recognition and response, where human voice commands direct simulation tasks, and agent-based communications can be heard.

The AEDGE was conceived through cognitive and functional analysis of team member roles, responsibilities, and decisionmaking (Chaiken et al, 2001), to optimize generalizability of results to operational settings. Systematic descriptions of AWACS roles, responsibilities, requirements, interdependencies, tactics, strategies, and task demands were collected from subject matter experts, cognitive task analyses (Fahey et al., 1998; MacMillan et al., 1998) and focal-group interviews (Elliott et al., 2001). These data were examined to identify decision events, which were generic to performance, regardless of mission scenario, and likely to bottleneck under high tempo situations.

The software, built using 21st Century Systems Inc.'s AEDGE infrastructure, is a distributed, real-time team decision support environment comprised of simulators, entity framework, intelligent agents and user interfaces. The environment supports a wide variety of air, sea (surface and sub-surface), and ground assets in a combat environment (Chiara & Stoyen, 1997), primarily based on the roles and responsibilities of AWACS WD team members. The environment has been tested with an excess of two hundred physical entities (planes, ships, SAM sites, etc.) operating with realistic yet non-classified performance characteristics in an interactive environment in which real-time decision support is available to each WD.

The behavior and decisionmaking of all hostile and friendly entities not controlled by humans is directed by agent-based technology. If a human decides to "log in" as a particular entity, he/she may choose to view recommendations generated by the agent for that entity. Even if the human operator chooses not to view recommendations, the agent recommendations are still logged by the computer. This enables direct comparison of human to agent decisionmaking. We expect these capabilities will facilitate skill acquisition, decisionmaking, skills assessment, and human/team performance modeling.

AEDGE agent capabilities enable more detailed and innovative approaches to measurement and modeling of individual and team workload, communication and decisionmaking. Tracking the number and type of recommendations generated by the agent at any given time contributes toward new ways of conceptualizing and representing cognitive workload of individuals and teams. Agent-based recommendations may also serve as a standardized benchmark by which human tactics and decisions can be compared. In addition, the AEDGE platform can operate through speech – operators can speak to the system using predefined jargon, request tasks be performed or information provided/transferred, and the agents will respond verbally to the speech-driven requests, using voice generation technology. All agent communications to each other, as well as to humans, are transcribed, logged to data output files, and are available online.

<u>UAV</u> A project at New Mexico State University (Cooke & Shope, 2002) deals with such technology in the realm of Uninhabited Aerial Vehicles (UAVs). The UAV Synthetic Task Environment (STE) was the first synthetic task designed for the Cognitive Engineering Research on Team Tasks (CERTT) Laboratory. The CERTT Lab's hardware design, development, and construction phases were being done in parallel with the UAV STE development. This permitted close developmental cooperation between this particular STE and the overall CERTT Lab design.

Cooke and Shope (In Review) briefly summarize the UAV is controlled by operators in a GCS (ground control station) who communicate with other groups concerning issues of data interpretation and airspace deconfliction. The major team members within the GCS include the AVO (Air Vehicle Operator) who operates the UAV, the PLO (Payload Operator) who operates

the sensors, and the DEMPC (Data Exploitation, Mission Planning, and Communications Operator) who is responsible for mission planning. These individuals work together to accomplish the goal of navigating the UAV to a position to take reconnaissance photos of designated targets. Individual team members have access to information about the UAV flight system, sensor equipment, and the surrounding environment, by way of computer displays, hard copies, and communication channels.

Cooke and Shope (in review) write that in their case, the STE was designed to serve as a flexible task environment for the development and evaluation of measures of team cognition. It was also to be located in New Mexico State University's CERTT laboratory. This overall goal resulted in the following three objectives: 1) the STE should facilitate the measurement of team cognition, 2) the STE should provide a realistic task environment, and 3) the STE should provide an experimenter-friendly research test-bed

Their resulting prototype consisted of seven interconnected systems (two for each of three team members and one for the experimenter), and for each system, a representation of the screen and detailed functional specifications.

<u>C3STARS</u> The Command, Control, Communications, Simulation, Training and Research System (C3STARS) facility offers the opportunity to investigate complex decisionmaking among interdependent team members within a dynamic and realistic setting. The crewstations and scenarios simulate the air defense mission of an AWACS platform. Realism is achieved through the functional representation of equipment and displays, experienced personnel playing the role of simulation pilots, and the use of operational scenarios.

Closed circuit video and audio stations permit experimenters to directly observe team interactions and remotely record all communications (computer, visual and audio) for later analysis. The unique simulations integrate hardware and software resources, data collection and analysis systems, verbal communication networks, command and control scenarios and team performance measures.

The capability of the facility is enhanced by connecting the crewstations to the Advanced Distributed Simulation (ADS) network – enabling assets at other DOD facilities to be integrated into multi-force simulation exercises.

The communication network takes advantage of advances in high speed digital signal processing, networking and communication architectures to provide a communication system that will grow with future technology. The network is also designed to support synthetic tasks requiring voice messages on low cost PC-based communication workstations. The system can be linked into the Internet with other government laboratories and universities.

<u>F-PASS.</u> The Flight-Performance Assessment Simulator (F-PASS) is an inexpensive desktop flight simulator designed to teach, evaluate, and select for piloting and situation awareness (SA) skills (O’Donnell & Moise, 1997, O’Donnell & Moise, in review). It is a multi-dimentional, theory based, dynamic measurement tool that can generate measures of SA, workload, skill level, stress training, etc. Its data can be validated against the ultimate criterion – mission performance.

Current scenarios are applicable to the performance of reconnaissance, surveillance, air-to-air, and air-to-ground missions in multiple threat environments, and range from minutes to hours in length. The F-PASS utilizes realistic aeromodels that currently represent the dynamic

characteristics of the F-16, T-38 and T-1 aircraft. The F-PASS also has the capability to add new aircraft and new scenarios to the system.

Latest Interoperability Tests

In December of 2001, a successful test was run linking the C3STARS, the UAV, and the FPASS simulators. The C3STARS and UAV simulators utilized T1 lines, while the FPASS used a 30K baud line. While connected, all 3 of the systems participated in an exercise. The FPASS accurately displayed both the UAV and the C3STARS generated entities. The C3STARS saw all entities involved.

As an example of how these varied simulators were integrated, the UAV found ground threats, and this data was sent to the C3STARS. The C3STARS then used this data to direct friendly forces, including both FPASS and C3STARS generated entities.

One limitation this test faced was the fact that the UAV was set to transmit data only. It did receive data from the C3STARS, but there was no way for it to utilize the data. Also, voice communications were sent over phone lines. Interest has been displayed at integrating voice communication into the network in the future.

In March of 2002, a separate test was run, this time successfully connecting the C3STARS entities and the AEDGE. This entailed one way communication from the C3STARS to the AEDGE. Position, heading, altitude, and identification data were all communicated, and all information was accurate with the exception of some problems with the heading information.

This test was not run in the reverse direction, with information going from the AEDGE to the C3STARS, although it is believed that it would likely work. Another potential advance would involve utilizing the AEDGE agent recommendation information and sending it to the C3STARS operator.

Summary

These efforts have shown the great potential that exists for the integration of simulators into a common network, one that can be utilized not only for training purposes but also for training research. Each of the UAV, FPASS, and C3STARS was developed independently, without plans for integration. However, tests have been successfully run showing them working together, generating and displaying entities from each of the various systems in a common battlespace. Integration barriers are being taken down, allowing for interoperability capabilities previously undreamed of. This will allow for high quality collaborative research, where the strengths of each simulator and platform is put to use in a complimentary way. The creation of this infrastructure is more than a demonstration of technology. First, the platforms themselves offer unique capabilities, regarding scenario realism, experimental control and performance measures to experimenters. The use of a common platform allows comparison of diverse programs of research, each focused on a different aspect of performance, albeit training, interface technology, information distribution, or fatigue countermeasures.

Even so, why connect the platforms? Certainly, the distribution and portability of these platforms have self-evident benefits for trainers—training can occur among distributed trainees, deployed in remote sites. But what is the benefit for researchers? First, there is great importance in performing research on multi-team system performance. Operational teams are often assigned ad hoc, with team members and teams having diverse perspectives and little

familiarity with each other. Distributed team research can capture these inherent differences faced by DMT teams. Teams in different locations would have diverse individuals, trained in diverse locations, with different curricula, by different trainers—thus capturing relevant and realistic diversity in operations.

In addition, operational DMT generates questions regarding the type and nature of joint mission planning, multi-team coordination, and joint debriefing procedures. DMT teams encompass diverse teams, such as cadres of fighter pilots, cargo and refueling aircrew, and various command and control platforms. DMT itself does not lend itself as well to experimental design. DMT resources are devoted more toward training in itself, subjects / resources are difficult to procure, and experimental manipulation more difficult to achieve, in a context rich in confounding variables and low in statistical power. The connection of diverse internet-based platforms allow university-based researchers to investigate questions of skill acquisition in multi-team context, to easily manipulate distribution and display of information and performance feedback, and to study processes of joint mission planning and debriefing. Thus, DMT-RNet will serve as a scientific bridge to for the enhancement of operational distributed mission training.

References

Barnes, C., Elliott, L., & Entin, E. (2001). Employing Internet2 Technology to Enable Collaborative Research and Distributed Training in Complex Multi-Operation Settings. Webnet Journal, October-December.

Berkowitz, L., & Donnerstein, E. (1982). External validity is more than skin deep: Some answers to criticisms of laboratory experiments. American Psychologist, 37 (3), 245-257.

Chaiken, S., Elliott, L., Dalrymple, M., & Schiflett, S., Coovert, M., Riddle, D., Gordon, T., Hoffman, K., Miles, D., King, T. (2001). Weapons Director intelligent agent-assist task: Procedure and findings for a validation study. Proceedings of the International Command and Control Research and Technology Symposium, June, 2001.

Chiara, J. & Stoyen, A. (1997). Intelligent, adaptive research and training platform for individual and team training, with web capabilities and applications. Phase II SBIR Report AF971-018. Brooks AFB, TX: Air Force Research Laboratory, Warfighter Training Research Division.

Cook, T., & Campbell, D. (1979). Quasi-experimentation: Design and analysis issues for field settings. Boston: Houghton Mifflin.

Cooke, N. J., & Shope, S. M. (In Review). Designing a Synthetic Task Environment.

Coovert, M., Riddle, D., Gordon, T., Miles, D., Hoffman, K., King, T., Elliott, L., Schiflett, S., & Chaiken, S. (2001). The impact of an intelligent agent on weapon directors behavior:

Issues of experience and performance. Proceedings of the International Command and Control Research and Technology Symposium, June, 2001.

Entin, E., Serfaty, D., Elliott, L., & Schiflett, S. (2001). DMT-RNet: An Internet-based Infrastructure for Distributed Multidisciplinary Investigations of C2 Performance . Proceedings of the 2001 Command and Control Research and Technology Symposium, Annapolis, MD, June.

Elliott, L. R., Dalrymple, M., Regian, J. W., Schiflett, S. (2001). Scaling Scenarios for Synthetic Task Environments: Issues Related to Fidelity and Validity. Paper to be presented at the 2001 Meeting of the Human Factors and Ergonomics Society, September.

Fahey, R. P., Rowe, A., Dunlap, K. and DeBoom, D.(in review). *Synthetic Task Design (1): Preliminary Cognitive Task Analysis of AWACS Weapons Director Teams*. Technical Report. Brooks AFB, TX: Armstrong Laboratory.

Hess, S., MacMillan, J., Elliott, L., & Schiflett, S. (1999). Team-in-the-Loop, Synthetic Simulation: Bridging the Gap Between Laboratory and Field Research. Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society, Houston, TX; 1999.

Kleinman, D. L. & Serfaty, D. (1989). Team performance assessment in distributed decision-making. Proceedings of the Symposium on Interactive Networked Simulation for Training (pp. 22-27), Orlando, FL.

MacMillan, J, Serfaty, D., Young, P., Klinger, D., Thordsen, M., Cohen, M., & Freeman, J. (1998). *A system to enhance team decision making performance: Phase 1 Final Report.* Brooks AFB: Air Force Research Laboratory, Warfighter Training Research Division.

Mook, D. G. (1983). In defense of external invalidity. American Psychologist, 379-387.

O'Donnell, R. D. , Moise, S. L., Eddy, D., & Shaw, R. (1997). *Development of a Standardized PerformanceTest Battery for Certification of Aeromedical Drugs I: Test Battery Description and Demonstration of Approach: Phase I Final Report.* Brooks AFB: Air Force Research Laboratory, Warfighter Training Research Division.

O'Donnell, R. D. , Moise, S. L., Smith, R., Cardenas, R., & Shaw, R. (In Review). *Development of a Standardized Performance Test Battery for Certification of Aeromedical Drugs, II: Final Development of the Flight-Performance Assessment Simulation System (F-PASS).* Brooks AFB: Air Force Research Laboratory, Warfighter Training Research Division.